Magnetic coupling in Co/Cu multilayers: field dependent antiferromagnetic ordering investigated by resonant x-ray scattering

Maurizio Sacchi [1], Carlo Spezzani [1], Piero Torelli [1], Coryn Hague [1,2]
Fahrad Salmassi [3], Stanley Mrowka [3], Eric Gullikson [3] and James Underwood [3]
[1]Laboratoire pour l'Utilisation du Rayonnement Electromagnétique, B.P. 34, 91898 Orsay (France)
[2]Laboratoire de Chimie-Physique – Matière et Rayonnement, 11 rue Pierre et Marie Curie, 75005 Paris (France)
[3]Center for X-Ray Optics, Ernest Orlando Lawrence Berkeley National Laboratory,
University of California, Berkeley, California 94720, USA

Layered metallic structures, alternating magnetic and non-magnetic layers, can display giant magneto-resistance (GMR) [1]. They are currently employed in data storage and retrieval devices, though some aspects of the mechanisms leading to GMR are still not well understood (see for instance ref. [2]). Among the most studied of such systems are Co and Cu multilayers. In magnetic multilayers of the type Co/Cu the thickness of the Cu spacer (t_{Cu}) plays a key role in the properties of these devices. In particular it determines the coupling in zero field between adjacent Co layers, that oscillates as a function of t_{Cu} between ferromagnetic (FM) and antiferromagnetic (AF), leading to corresponding low and high magnetoresistance states. At t_{Cu} ~9 Å (first AF peak), GMR can be up to 30% for applied fields of the order of 500-1000 Oe. At the second AF peak (t_{Cu} ~20 Å), GMR is usually smaller (10-15 %), but, due to the weaker AF coupling, the effect can be obtained at lower external fields (100-200 Oe), which makes this Cu thickness more attractive for many applications. Several experimenters reported that the magneto-resistance may be irreversibly altered by the application of a magnetic field strong enough to force the parallel coupling of all the Co layers, and the GMR value of the as-prepared sample cannot be restored by field cycling or demagnetization. This phenomenon has been studied recently by Borchers *et al.* [2] using polarized neutron reflectivity. The information they obtain suggests that there is no magnetic correlation between adjacent Co layers after cycling the sample, as opposed to almost complete anti-ferromagnetic coupling in the as-prepared state.

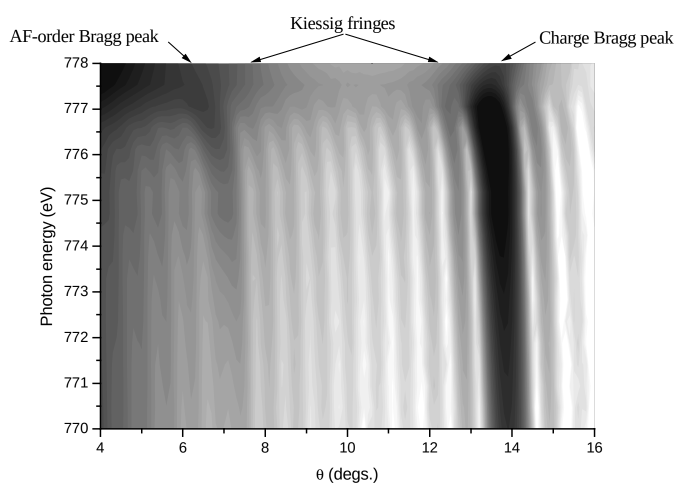

Figure 1. Energy and angle dependent scattered intensity for the as-prepared sample.

The purpose of this study is to employ x-ray resonant magnetic scattering (XRMS) to investigate the interplay between microstructure and magnetic behavior. Resonant scattering of polarized x-rays (both linear and circular) is sensitive to ferromagnetic and antiferromagnetic ordering and is thus ideally adapted to elucidate such behavior as a function of the Cu layer thickness.

First experiments were performed on three samples prepared at the Center for X-Ray Optics (Lawrence Berkeley Lab.) with Cu thickness values of 22, 40 and 90 Å. In the following, we will concentrate on the t_{Cu} = 22 Å sample (second AF peak), whose structure is $(Cu_{22}/Co_{11})_{20}$ / Si. XRMS measurements were performed on the x-ray metrology beamline 6.3.2 of ALS, using the reflectometer endstation. We selected out of plane radiation in order to have a high degree of circular polarization (60-70 %). The sample was mounted on an electromagnet, with the field direction at the intersection between the sample surface and the scattering plane. The scattered intensity was collected as a function of photon energy, scattering angle and applied field. Electrical measurements were performed ex-situ with the samples mounted on the same electromagnet. Close to a core resonance, where optical constants vary strongly with photon energy, XRMS becomes element selective and sensitive to electronic properties and magnetic ordering. For the as-prepared $(Cu_{22}/Co_{11})_{20}$ / Si sample, we have measured, at the Co 2p resonance, a strong Bragg peak corresponding to half the multilayer period, whose intensity varies with photon energy (Fig.1). The resonant scattering factor of Co depends on its magnetic orientations, and this ½ order Bragg peak originates directly from the antiferromagnetic coupling between adjacent Co layers which induces an extra periodicity with an order parameter double that of the multilayer. First we have identified the photon energy and scattering angle conditions enhancing the AF Bragg peak (Fig. 1), and then we have followed its evolution as a function of the applied field.

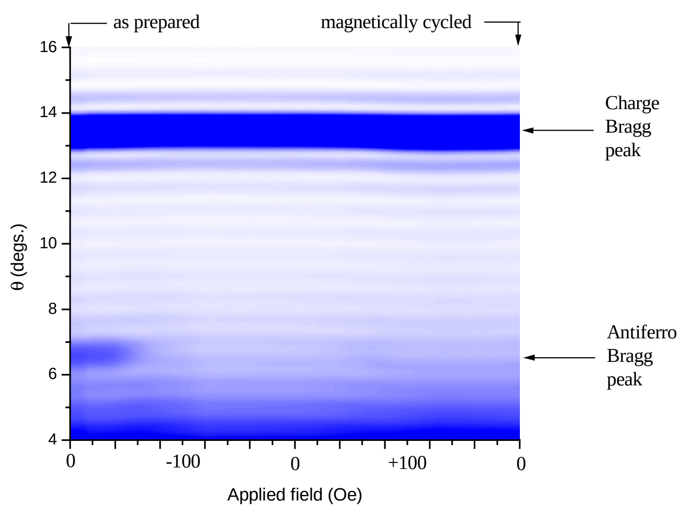

Figure 2. Angle and field dependent scattered intensity at hν=776.5 eV.

The slight displacement of the main Bragg peak and of the Kiessig fringes that can be observed in Fig. 2 at a field of about 75 Oe is induced by the switching to a dominant FM coupling between Co layers, as also shown in Fig. 3. Our results clearly indicate that the complete AF ordering observed in the as-prepared multilayers is irreversibly destroyed by magnetic cycling the sample up to about 100 Oe (Fig.2). After cycling, the AF peak is strongly reduced, indicating that complete ordering through the entire stack of layers is lost to a large extent. This conclusion is supported by the curves in Fig. 3, where the scattered intensity at 6.7° and 776.5 eV (maximum of the AF Bragg peak) is reported as a function of the applied field. It is important to point out that Fig. 3 contains two sets of curves (black/red/green and blue/pink) obtained on two different as-prepared samples cut from the same batch. The first set represents a series of minor cycles with increasing maximum applied field. In the second set, the as-prepared AF sample is brought to the FM state by applying a field of 150 Oe, and then cycled between –150 and 150 Oe. It is interesting to observe that before reaching a stable and reproducible behavior, the sample has to go through the entire 0 / 150 / -150 / 0 Oe cycle.

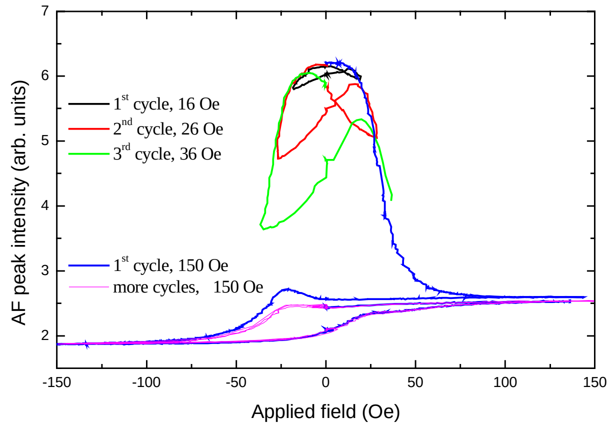

Figure 3. Scattered intensity at 6.7° and 776.5 eV versus the applied field. Two sets of data are reported, obtained starting from two different as-prepared samples.

The analysis of these results is in progress. It is already clear that there is a strong correlation between the alteration of GMR characteristics and our observation of cycle dependent AF ordering. As an example, Fig. 4 shows the resistance of the sample versus the external applied field.

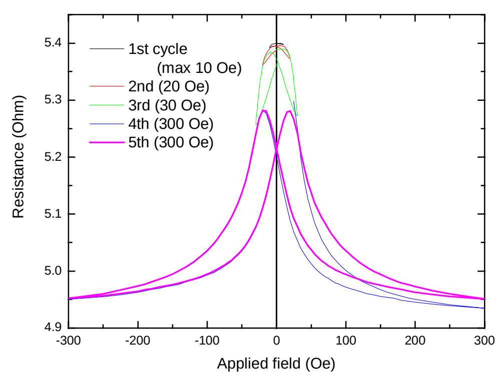

Figure 4. Resistance versus field starting from an as prepared sample.

REFERENCES

1. Baibich *et al* Phys. Rev. Letters **61**, 2472, (1988)
2. Borchers *et al* Phys. Rev. Letters **82**, 2472, (1999)

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Principal investigator: Maurizio Sacchi, LURE, BP 34, 91898 Orsay (F). Email: sacchi@lure.u-psud.fr. Telephone: +33.1.64.46.80.89